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A SYSTEMS ENGINEERING EVALUATION METHOD FOR PILOTED AIRCRAFT AN--ETC(U)
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ADDENDUM

TO
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A SYSTEMS ENGINEERING EVALUATION METHOD FOR PILOTED AIRCRAFT AND OTHER MAN-OPERATED VEHICLES AND MACHINES

APPENDIX D

A Unifying Set of Hypotheses for Dynamic System Test and Evaluation: The Rating and Measurement of System Performance, System Load, and System Work and Their Interrelationships

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APPENDIX D

A UNIFYING SET OF HYPOTHESES FOR DYNAMIC SYSTEM TEST AND EVALUATION: THE RATING AND MEASUREMENT OF SYSTEM PERFORMANCE, SYSTEM LOAD, AND SYSTEM WORK AND THEIR INTERRELATIONSHIPS.

SUMMARY

A set of equations, definitions, symbols, units of measurement and an equal interval scale providing an equal interval unit rating and measurement method for system evaluation are presented.

The objective is to provide a unified approach to the systems engineering evaluation, rating and measurement of a dynamic system.

The equations present the hypothesized relationships between system ratings and system measures of performance, work, and load.

An equal interval, one-tenth power of ten, scale with ten as the highest rating is introduced for the rating, measuring, and communicating system performance, work, and load factors. These factors are of increasing interest during early R&D system dynamic simulation concept testing and later operational system test and evaluation.

INTRODUCTION

The following definitions, symbols, and equations are proposed to provide a common method of communicating the complex relationship

between ratings and measures of system performance, system load, and system work during dynamic system test and evaluation.

DEFINITIONS

System: A system exists in its simplest form when one person uses a piece of equipment to perform a useful function.

System Evaluation: The functioning of the system is assessed against system criteria to determine qualitatively and quantitatively the degree to which the operating system meets these standards.

System Evaluation Methodology: The design, conduct, and analysis of dynamic human operated equipment tests so as to provide a true assessment of the systems functional utility.

Systems Performance: A summation of the ratings and measures of system output which correlate highly with systems criteria. Systems performance is hypothesized to be qualitatively and quantitatively equal to and varies inversely with system load and system work.

System Load: The input load imposed on the system during operation designed to accomplish its useful function. It is hypothesized to be qualitatively and quantitatively equal to and varies directly with system work; therefore, the relationship explains

the probable origin of the misnomer in the venacular of everyday slang and common usage of the term "workload".

System Work: Not only the useful output of system equipment as defined in physics, but the effort required of a person to handle the system load. It may correlate with physiological measures such as heartrate. It is hypothesized to be qualitatively and quantitatively equal to and varies directly with system load; therefore, this relationship explains the probable origin of the misnomer in the venacular of everyday slang and common usage of the term "workload".

System Criteria: The statement of the ultimate standards by which a systems performance is judged and measured. Generally, a statement of the systems goals. For example, the safe, orderly, and efficient control of air traffic used as the criteria for evaluating an Air Traffic Control System.

Baseline or Standard Conditions: The optimum rating and measure of system performance obtained under conditions of optimum system load and optimum system work. It is quantified as being 100 percent, zero decivals, and a system evaluation rating of ten, 10.

Decival, dv: A decival is a proposed system evaluation unit of measurement which is 10 times the logarithm of equal interval system differences which are plus or minus one-tenth powers of ten apart.

Decival, dv (Continued)

$1 \text{ dv} = 10 \log [10^{0.1}]$ and $-1 \text{ dv} = 10 \log [10^{-0.1}]$

This change is equal to one rating unit along the one-tenth power of ten scale shown in figure 1.

Centival, cv: A centival is a system evaluation unit of measurement which is 10 times the logarithm of the equal interval distances which are one-hundredth powers of ten.

$1 \text{ cv} = 10 \log [10^{0.01}]$ and $-1 \text{ cv} = 10 \log [10^{-0.01}]$

A System Factor Rateable Difference: The hypothesized smallest noticeable difference in system performance, work, and load which approximates a measured change of one centival. This change is equal to one-tenth of a rating unit along the one-tenth power of ten scale shown in figure 1.

System performance, work, and load factors: Those system measures which are proven by operational test results to correlate highly with magnitude estimation ratings of system performance, work, and load. These ratings may be obtained from operators of the systems and/or expert operators observing the system operation and using an equal interval ($10^{0.1}$) rating scale shown in figure 1.

System performance, work, and load measures: Twenty-eight operationally defined and measurable changes in air traffic control system performance are discussed in reference no.2,

The FAA Handbook for Experimenters. They are formed to fall into clusters of measures called factors such as the number and duration of conflicts, delays, communications, etc., which correlate highly with system performance ratings. These same measures are hypothesized to also correlate highly with the ratings of system work and the effort required of the controller to handle the system load and meet system criteria. System load measures of the number of aircraft handled and system airspace sector size and geometry are hypothesized to correlate highly with system load factor ratings.

SYMBOLS

P System performance

P_{dv} System performance measures in decivals, dv.

dv A decival, equal to $10 \log_{10} \left[X_1/X_0\right]$, where X is a measured system evaluation factor and X_1/X_0 is the ratio of change measured in that factor during the period when it is being observed and rated.

P_R System performance rating.

R An equal interval numerical method of rating of system factors (performance, work, load, etc.) ranging from ten at the highest downward to one at the lowest on an equal interval scale. The one-tenth power of ten scale has values of $10^{\pm 0.1}$ between units and $10^{\pm 0.01}$ between tenths of rating units as shown in figure 1.

L Load on the system.

L_{dv} System load measure in decivals, dv.

L_R System load ratings.

W System work including human effort required to handle system load and meet system performance criteria.

W_{dv} System work measure including human effort required to handle system load and meet system performance criteria in decivals, dv.

W_R System work rating including the human effort required to handle system load and meet system performance criteria.

<u>EQUATIONS: SYSTEM EVALUATION HYPOTHESES</u>

$$P_{dv} = P_R - 10 \qquad (1)$$

$$L_{dv} = 10 - L_R \qquad (2)$$

$$W_{dv} = 10 - W_R \qquad (3)$$

$$P_{dv} = 10 \log [\Delta P/P] \qquad (4)$$

$$L_{dv} = 10 \log [\Delta L/L] \qquad (5)$$

$$W_{dv} = 10 \log [\Delta W/W] \qquad (6)$$

$$P_R = 10 + 10 \log [\Delta P/P\%^*/100] \qquad (7)$$

$$L_R = 10 - 10 \log [\Delta L/L\%^*/100] \qquad (8)$$

$$W_R = 10 - 10 \log [\Delta W/W\%^*/100] \qquad (9)$$

*As these are magnitude estimation ratings of system performance, P load, L, and work, W based on a standard optimum rating of 100%, as shown in figure 1, they are percentage ratings. Therefore, in this equation percentage ratings must be divided by 100. This provides the fractional expression of the rating which is hypothesized to be equal to the ratio of the measured values of the observed system performance, system work, and system load factors compared to the measured standard, ultimate 100% performance, work, and load factors.

DISCUSSION

An equal interval, one-tenth power of ten ($10^{\pm 0.1}$), with ten the highest rating is introduced to unify both the rating and the measurement of system factors of interest during system evaluation. The quantitative value of the interval between units of this scale is designed to be constant. Throughout the scale, it is always plus or minus the one-tenth power of ten ($10^{\pm 0.1}$) of the system factor being rated or measured.

Ten times the logarithm base ten is termed a decival, dv. The scale is further divided into tenths so that one-tenth of the distance between units is always equal to plus or minus the one-hundredth power of ten, ($10^{\pm 0.01}$) of the factor being rated or measured.

Ten times the logarithm of these one-tenth unit distances or 0.1 dv is termed a centival, cv. A centival is hypothesized to approximate the smallest perceived and therefore rateable difference in any system factor being rated.

A verbal rating is assigned to each unit of the scale to provide a qualitative, general descriptive statement of the type and degree of rated and measured system performance, work, and load found during the system evaluation.

The method does not require or depend on the use of 10 times logarithms of system measures and ratings. However, it is recommended for adoption and general use as it provides a simple useful

way of dealing with the quantitative statement of the value of the underlying basic equal interval scale. The key is the equal interval written and communicated as powers of 10, i.e., $10^{\pm 0.1}$ and $10^{\pm 0.01}$, etc.

Ten times the logarithm of these powers of 10 is only a shorthand way of referring to them as the decival, dv and the centival, cv. These units have the advantage of being plus or minus so many decivals or centivals which are easily perceived as being equal intervals. These intervals represent equal fractions (Δ X/X) of change and equal percentages of change when multiplied by 100.

Thus, the centival or decival provides a simple way of communicating equal intervals of change, increasing or decreasing in relation to the baseline or standard condition.

The standard or baseline system conditions of qualitatively optimum system performance, work, and load required to meet system criteria are quantified at 100%, zero decivals and a rating of 10. In the Air Traffic Control System, these system criteria or ultimate goals are the safe, orderly efficient flow of air traffic.

The basic nature of the system evaluation scale is to depict changes from the standard system condition in equal intervals of system performance, work, and load. As system load increases $10^{0.1}$ or one decival (1.0 dv) so does the system work required increase

$10^{0.1}$ or 1.0 dv; however, system performance has degraded $10^{-0.1}$ or -1.0 dv. This relationship between rated and measured system load, system work, and system performance is continuous throughout the scale.

For example, as load increases to $10^{0.3}$ or 3 dv, so does system work or effort required of the operator representing a doubling of each from the baseline measured and rated conditions. In turn, system performance has changed by $10^{-0.3}$ or minus 3 dv. This represents a halving of system performance from the baseline systems measured and rated conditions.

The system rating R has also changed 3 rating points to a 7 representing a good system. A further change of 3 dv increase in system load and work represents another doubling of each and further halving of system performance, -3 dv. The system rating R has decreased a further 3 rating points to a 4 representing an unsatisfactory or bad system.

The qualitative verbal rating is, of course, an approximation of the quantitative measured values which will be determined by system tests. It may prove to be a perfect fit of language to measured results. By use during system tests, the descriptive language may be calibrated and changed very easily, if necessary, until the fit is proven reliable.

The verbal rating may be the least important part of the system evaluation process. Even so, it is the bottom line method of

communicating test results by qualitatively verbalizing the results of the evaluation of a system.

The important parts of the system evaluation process are the simultaneous measurement and rating of system load, work, and performance. The potential discovery and proof of the hypothesized interrelationships among these system factors, their rating and their measurement depends on the use of an equal interval rating and measurement scale.

The scale must possess other attributes along with being equal interval throughout. It must communicate qualitatively and quantitatively the standard baseline condition. A percentage approach with 100% assigned to the standard and the word optimum along with a rating number R of 10 satisfies these requirements. It has the further advantage of providing a magnitude estimation psychopyhsical scaling technique basis to the scale. The late Dr. S. S. Stevens originated and proved the power of magnitude estimation (Reference No. 1). The percentage figures communicate this feature. Additional descriptive language is throughout the scale to reflect commensurate quantitative changes assigned. All of these scale features are useful not only for the system ratings, but also for the measurements of system performance, work, and load. The percentage and decival changes in system measures in relation to the measured and rated baseline condition can also be established by the system test. The relationship, or multiple correlation, of these measures to the verbal and numerical ratings may then be

established. This system evaluation process provides a common baseline and a common scale. Most important is the common relationship of measures and ratings in time as they are both obtained simultaneously throughout the system test.

At this point, a properly designed and conducted system evaluation as discussed in the FAA Handbook for Experimenters (Reference No. 2) will provide results anchored to a qualitative definition of what is optimum, excellent, very good, good, fair, poor, or bad system performance. Along with this will be established what constitutes optimum, light, moderate, considerable, extensive, great, or very great system work and load.

All of the above, at this time, are unknown qualitative and quantitative relationships among system performance, system work, and system load factors. They can be established by employing this method during dynamic system test and evaluation.

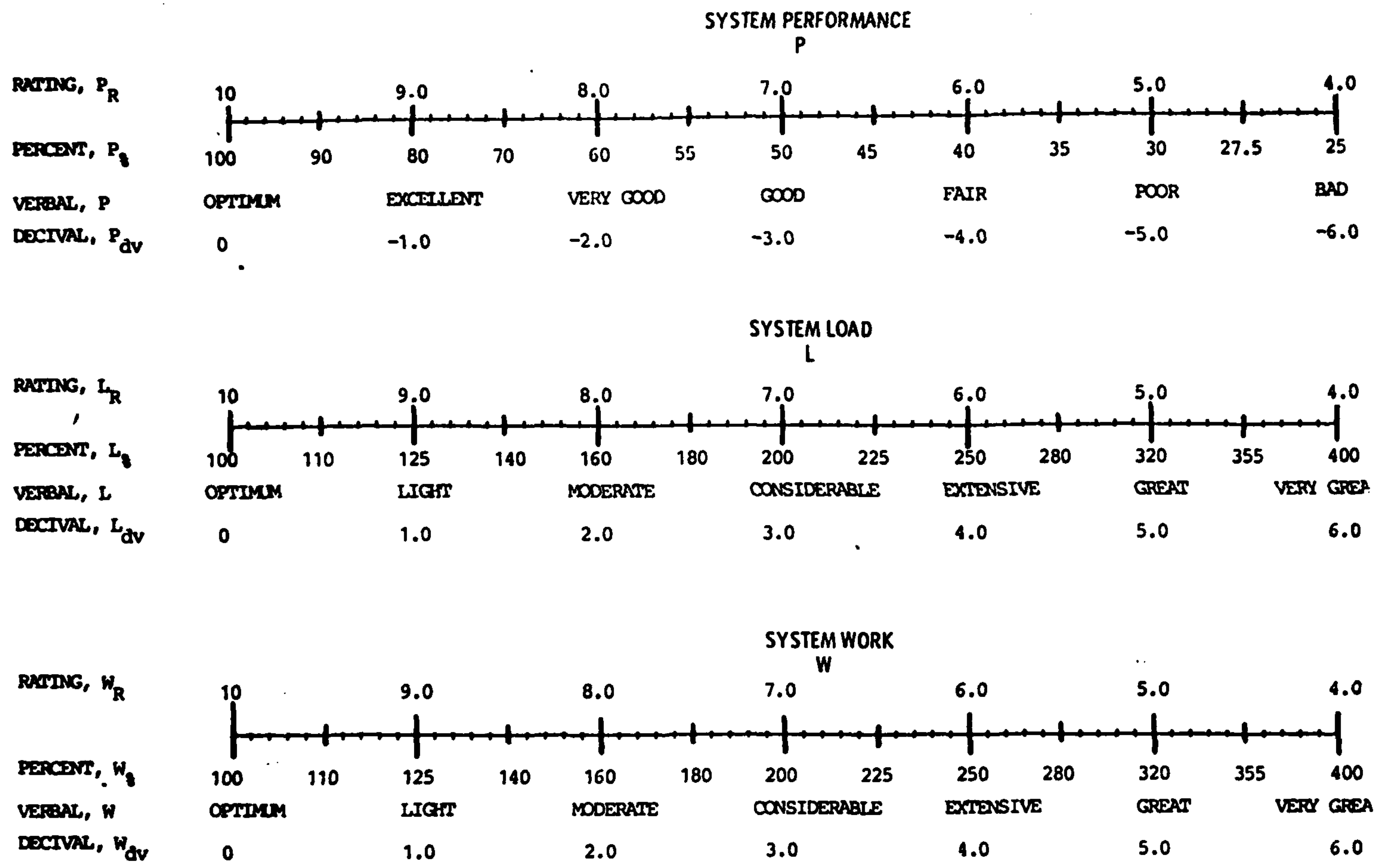

Figure 1. An example of an equal interval rating and measurement scale for system evaluation of performance, work, and load.

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